NEHRP FINAL TECHNICAL REPORT, 2005

USGS External Grants 05HQGR0057 (Nelson) and 05HQGR0066 (Goldfinger)

Title: Holocene Seismicity of the Northern San Andreas Fault Based on Precise Dating of the Turbidite Event Record. Collaborative Research with Oregon State University and Granada University.

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ABSTRACT

Numerous turbidites along the northern California continental margin are influenced by the northern San Andreas Fault (SAF). Our research focus is to: 1) analyze recurrence times of Holocene turbidites as proxies for earthquakes on the northern California active margin; 2) compare the age, frequency, and recurrence time intervals of turbidites using two methods: a) radiometric dating, (^{14}C method) and b) relative dating, using hemipelagic sediment thickness and sedimentation rates (H method) and 3) compare the paleoseismic records of northern California and Cascadia

active margins where the ^{14}C and H methods have been applied. The temporal correlations are supported by stratigraphic correlations using geophysical property data from the cores.

FY 2005 Investigations Undertaken

The objective of this project is to confirm the hypothesis that turbidites deposited in channel systems along the northern California continental margin resulted from turbidity currents triggered by earthquakes on the northern San Andreas Fault and to probe that the northern San Andreas might be a good locality to test the method sand hypotheses of turbidite paleoseismology previously applied to Cascadia. During our 1999 Cascadia cruise, we collected two piston cores and one box core from Noyo Channel, 150 km south of the southern end of the Cascadia subduction zone. During June and July, 2002, we collected 69 piston, gravity and jumbo Kasten cores from channel and canyon systems draining the northern California margin on the Scripps vessel R/V Roger Revelle. We operated with an international science party of 37 scientists and students from the US, Russia, England, France, Belgium, Germany and Spain. We mapped previously unmapped channel systems with the new Simrad EM-120 multibeam sonar recently installed on the Revelle.

During the cruise, we sampled all major and many minor channel systems extending from Cape Mendocino to just north of Monterey Bay. Sampling both down and across channels in some cases was done, and particular attention was paid to channel confluences, as these areas afford opportunities to test for synchronous triggering of turbid events. While at sea, all cores were scanned using the OSU GeoTek multisensor track core logger (MST), which collects p-wave velocity, gamma-ray density, and magnetic susceptibility data from the unsplit cores. Cores were then split, and run through the MST again to collect high-resolution line-scan imagery. After the MST runs, cores were sampled with a high-resolution magnetic susceptibility probe at 1cm intervals, then were hand logged by sedimentologists. The principal use of physical properties is as grain-size proxies. The internal depositional pattern, including sandy intervals, muddy turbidite tails, bioturbated intervals and hemipelagic clay can be distinguished in the magnetic and density logs in conjunction with the supporting X-ray, image, and lithologic log data. We are using density, color reflectance, and magnetics data as a proxy for determination of the turbidite tail-hemipelagic boundary to enhance the hemipelagic sediment analysis.

Samples for micropaleontology were taken and analyzed in real-time, providing a rapid determination of how deep into the Holocene or Pleistocene each core had penetrate. At sea and in laboratories at OSU samples were taken for mineralogy, and were analyzed for heavy minerals to attempt to distinguish channel systems by their mineralogic characteristics.

We continue our radiocarbon dating and analysis of physical property signatures as we work toward a stratigraphic framework for the Northern San Andreas System. At University of Granada, we are working with a semi-independent time series for SAF events based on the hemipelagic sediment thickness (H) deposited between turbidite events.

The turbidite record for the northern San Andreas Fault, in general, is more difficult to assess because: 1) there are no good regional datums like Mazama ash or consistent Holocene to Pleistocene faunal changes to correlate turbidites, 2) the turbidites are more difficult to distinguish visually in the upper part of cores because colors are less distinct between the hemipelagic and turbidite tail sediment and 3) the amount of compaction varies for different coring systems . Where age data are missing, sedimentation rates and hemipelagic intervals alone can be used. Ages calculated in this way can substitute for undatable events, and serve as a check on the ^{14}C ages. Using ^{14}C ages modified by the OxCal methodology, we have done a parallel H analysis for Noyo Channel obtaining recurrence times and ages based on hemipelagic sediment thickness (Fig. 2, Table 1, and Appendix 1). The basic methodology to obtain these recurrences follows the same techniques used in Cascadia Basin, except that for the Noyo Channel data we do not use Cal. yr B.P. ages. Instead, we use ^{14}C ages modified by OxCal with all the constraints included (sampling depth, erosion, and hemipelagic sediment thickness). The same analysis has been done for each core independently because each one has a different compaction rate. As in Cascadia Basin, at the Noyo location the hemipelagic sediment thicknesses were measured between the turbidite events in cores 49 PC/TC, 54KC and 50BC and an independent analysis of recurrence interval times for each core was done considering its individual compaction rate. The total H is added to obtain the cumulative H and the sedimentation rates are calculated using OxCal ^{14}C ages. The sedimentation rates are calculated using a moving window. The recurrence

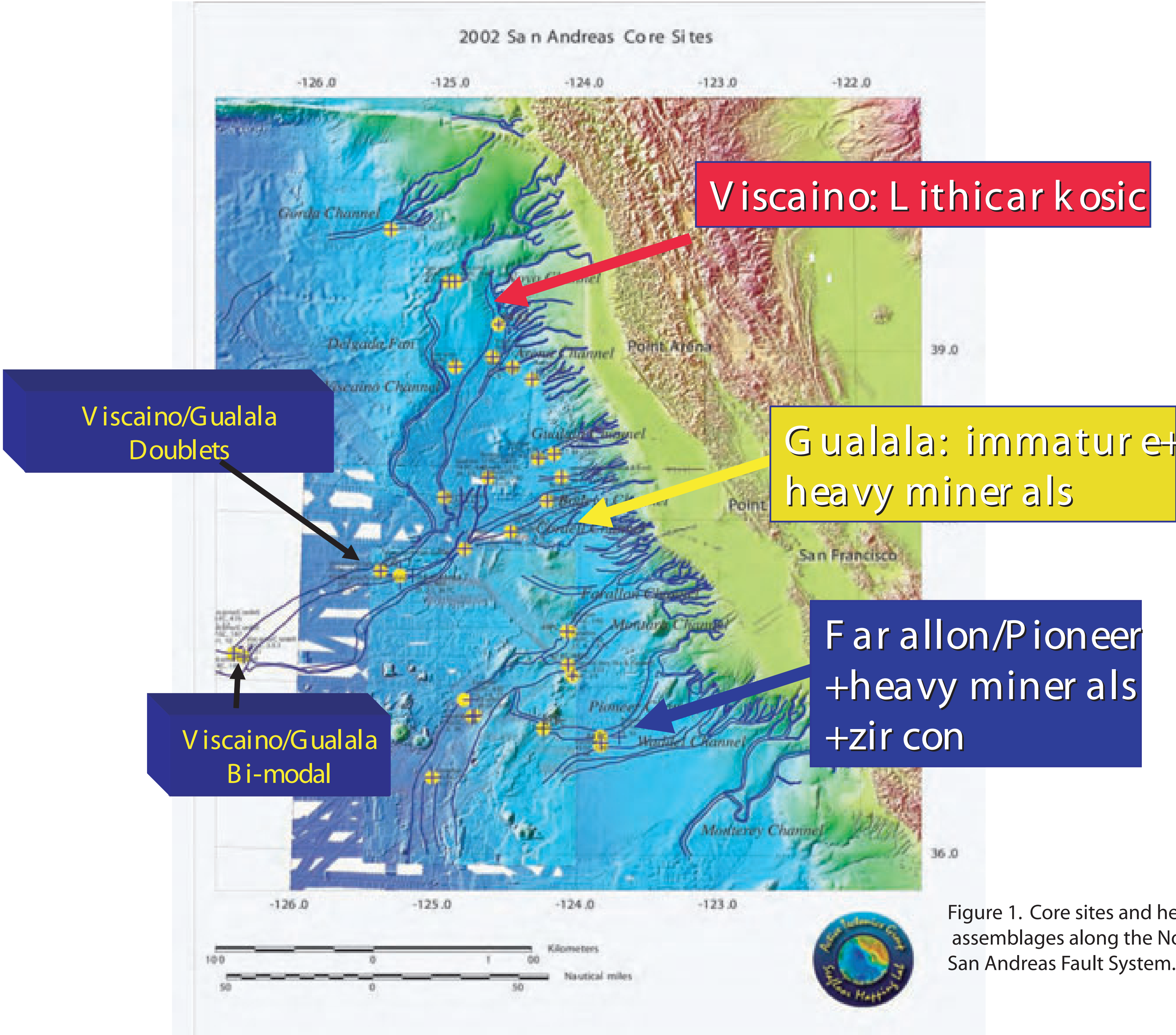

Figure 1. Core sites and heavy mineral assemblages along the Northern San Andreas Fault System.

times were then averaged for each correlative turbidite. In some cases we average the recurrence times from three cores and in cases where one core has an extreme value, the average is based on two cores (except for events one and two where 4 recurrences are averaged) (Table 1). To obtain H ages we follow the same procedure used for Cascadia Basin. For OxCal ^{14}C recurrence times, we determine the time between each set of correlative turbidites.

In FY 2005 at University of Granada we continued refining the new techniques based on the thickness of hemipelagic sediment between turbidites (H). These techniques can be used to independently evaluate and correct the AMS radiocarbon (^{14}C) ages because of the following reasons:

- The deep sea provides an independent time yardstick derived from a constant rate of hemipelagic sediment deposited between turbidites.
- Hemipelagic thickness/sedimentation rate = years which provides a set of turbidite recurrence times and ages to compare with similar ^{14}C data sets
- H can be used to evaluate data reliability (e.g. correct ^{14}C ages for sampling depth and erosion of sampled interval).
- H data is available for every turbidite event from multiple cores at each location compared to a single incomplete set of radiocarbon ages at each location.

FY 2005 Results

Channel Confluences and Mineralogy:

Unlike Cascadia, the Northern California margin does not appear to have a strong regional stratigraphic datum, thus correlating events and testing for an earthquake origin depends more heavily on stratigraphic correlation, and tests of synchroneity. Preliminary mineralogic data suggest a synchronous origin for at least some of the events examined thus far. We have been able to distinguish three heavy mineral provenances in the cores, well linked to the onshore source geology (**Figure 1**).

Channels from these distinct provenances come together at confluences on the abyssal plain, below which we clearly see mixed provenance, or stacked and distinct layers of the components of provenance represented in the tributaries. Rather than separate events from each provenance, we see either doublets and triplets, with no hemipelagic sediment between the events, or bimodal coarse fractions in the more distal turbidites, each peak representing a separate provenance (Goldfinger et al., 2004; Morey-Ross et al., 2003). Cores 24-31 downstream of the confluence show this

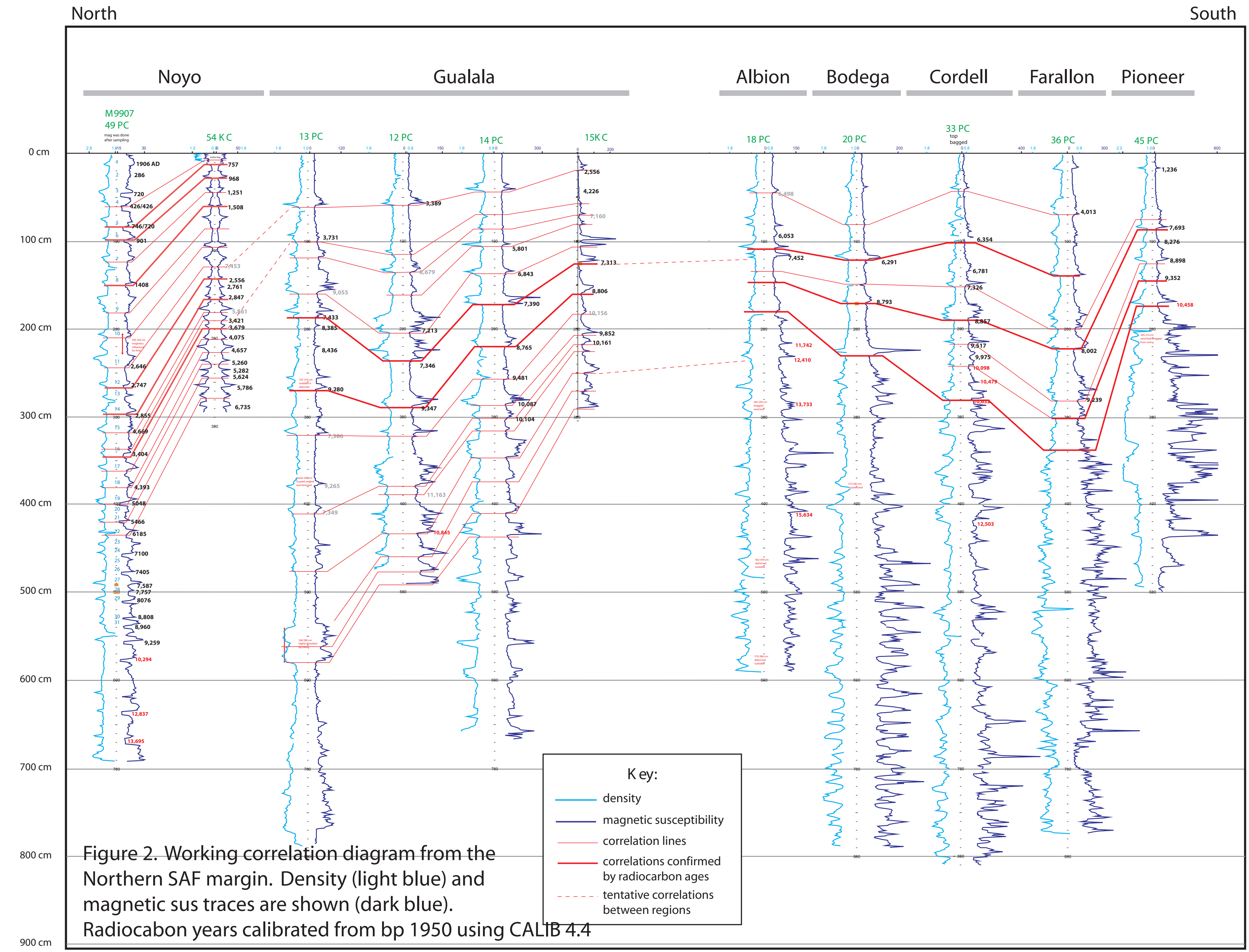

Figure 2. Working correlation diagram from the Northern SAF margin. Density (light blue) and magnetic sus traces are shown (dark blue). Radiocabon years calibrated from bp 1950 using CALIB 4.4

relationship. Although we do not yet have radiocarbon ages, we see that if the correlations are correct, the total number of events in a given span of the cores both above and below the confluence remains the same. If this is correct, events at this confluence pass a strict test of synchroneity, and we would argue they must be of earthquake origin. The use of mineral provenance to fingerprint source channels to test for earthquake origin has also been used in the Sea of Japan by Shiki et al. (2000).

Physical Property Correlation:

In the course of investigating turbidites along the Cascadia and San Andreas margins using offshore cores, we have acquired continuous high resolution magnetic susceptibility, Gamma density, P- wave velocity, and color reflectance data for all of the SAF cores. We have found that it is possible to correlate the physical property signatures of individual turbidites from locale to locale down individual channels. This indicates that the details of the turbid flow that are relevant to deposition of the turbidite, apparently maintain their integrity for long distances within channels. This in itself is somewhat surprising, but what is more surprising is that we have been able to correlate event signatures not only down individual channels, but between channel systems, some of which never meet. **Figure 3** shows several examples of individual event correlation and correlation of groups of events from the SAF system. We see a sometimes remarkable similarity between events that are separated by as much as 400 km in space. We see a general correspondence of turbidite size that is reflected in these separate channels, as well as correlatable details such as the number of coarse pulses (density and magnetic peaks). For example, in the Cascadia work which is nearly complete, events T5, T10, and T12 are small events in all cores at all sites. T11 and T16 are very large events in all cores, and most other events follow similar size patterns across the margin. We observe similar patterns in our SAF cores thus far. This information suggests that there may be some fundamental relative size relationship to either the underlying earthquakes, or alternatively perhaps to sediment supply events such as climate events or volcanic eruptions. Whatever the underlying reason, we have been able to use these persistent characteristics to build a correlation method.

Figure 3 shows an in-progress correlation diagram for the margin near the Noyo River. The correlation we see between events also suggests that there may be some persistent signature of individual events beyond their size that is recorded in the cores. The correlations often reveal very detailed pattern matching that is very surprising to us.

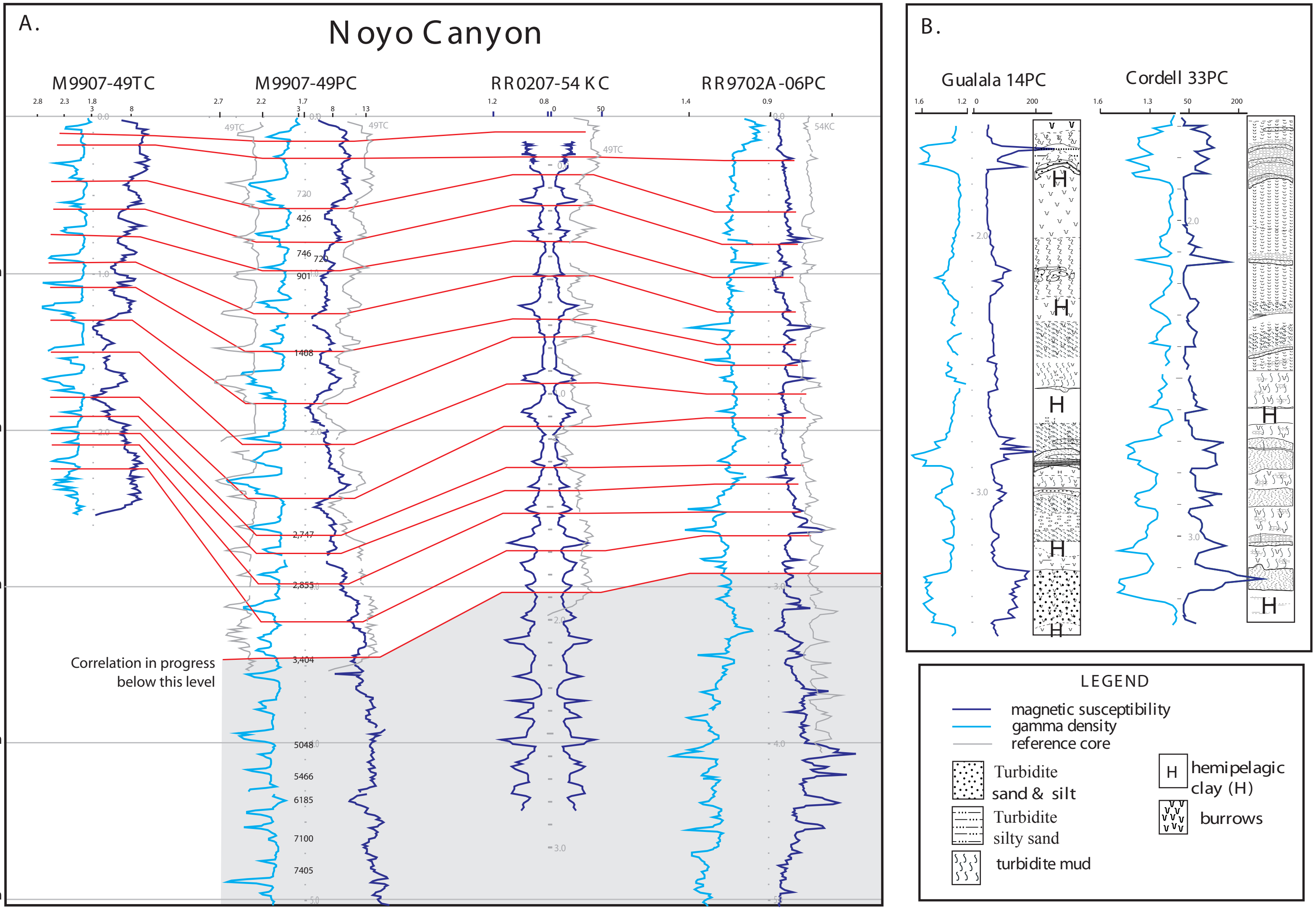

Figure 3. A. In-progress correlation diagram for Noyo Canyon cores (top 500 cm shown). Gray lines indicate geophysical data from adjacent cores used to identify correlations. These lines have been modified slightly to place correlative events next to one another. B. Detailed panel showing physical property data and corresponding lithologic diagrams for a correlative series of turbidites from three pairs of cores. Light blue (left) plots are Gamma density, the dark blue (right) plots are magnetic susceptibility. Note the correspondence of size, general character and number of peaks between events in the geophysical data and between the lithologic logs in the correlative pair in B. These correlations offer an independent method of event correlation in addition to radiocarbon ages. We infer that successful correlation also corroborates earthquake origin. See text for details.

Why should this be the case? A full discussion is beyond the scope of this report, and is the subject of a separate investigation, however we briefly speculate about the following hypothesis. The magnetic-density event signatures we see are created by sand rich layers, mostly in the base of the turbidite. These layers include heavy (dark) minerals such as magnetite and hematite, which are largely responsible for the signatures. This is clear from the high resolution imagery and x- rays, which show an obvious correlation between, density, magnetic susceptibility, and the coarse stringers in the turbidite for which we have done some heavy mineral analyses (**Fig. 3**; Goldfinger et al., 2003a,b). The correlation of these signatures indicates that the integrity of the signatures, and thus the pattern of coarse fraction deposition appears to be maintained to some extent over time and distance during the turbid event. One might expect that such correlation could be due to details of how the turbid flow initiated in the canyon's upper reaches. An earthquake, unlike other triggers for submarine landslides, is likely to trigger multiple failures within a canyon. Thus the turbid flow should contain multiple inputs, each perhaps containing a coarse fraction pulse, which coalesce down-channel. This could explain the persistent pattern we see within channels as reflecting the original multiple source input. But we are still left with the problem: Why do they correlate beyond an individual channel system, to other channels with different pathways, different sediment characteristics, and even different geology? We suggest then that the only plausible commonality between correlatable events in separate channels, is the original earthquake itself. We postulate that the physical property signatures may record elements of the shaking imparted to the sediment source region by the earthquake itself, in effect they may be crude paleoseismograms, imparting some information about magnitude, source character, or aftershocks to the sediment record. If so, such input must then be more significant than the failure pattern in the canyon as described above.

We speculate that multiple segment ruptures, or subevents within a mainshock such as that recently observed for the Sumatra M9 earthquake may result in multiple turbidite coarse fraction pulses that we seen in our cores. We have made a preliminary correlation of many of these events along the length of the SAF margin **Figure 2**. Radiocarbon ages from the new cores are still pending as of this writing. If correct, our initial correlations along strike imply rupture lengths for some events of > 300 km, similar to the 1906 event. There are also events that correlate only in the south, and several occur only in the north, suggesting a partial rupture mode in addition to long ruptures. The shorter correlations are as likely to be earthquakes as the longer ones,

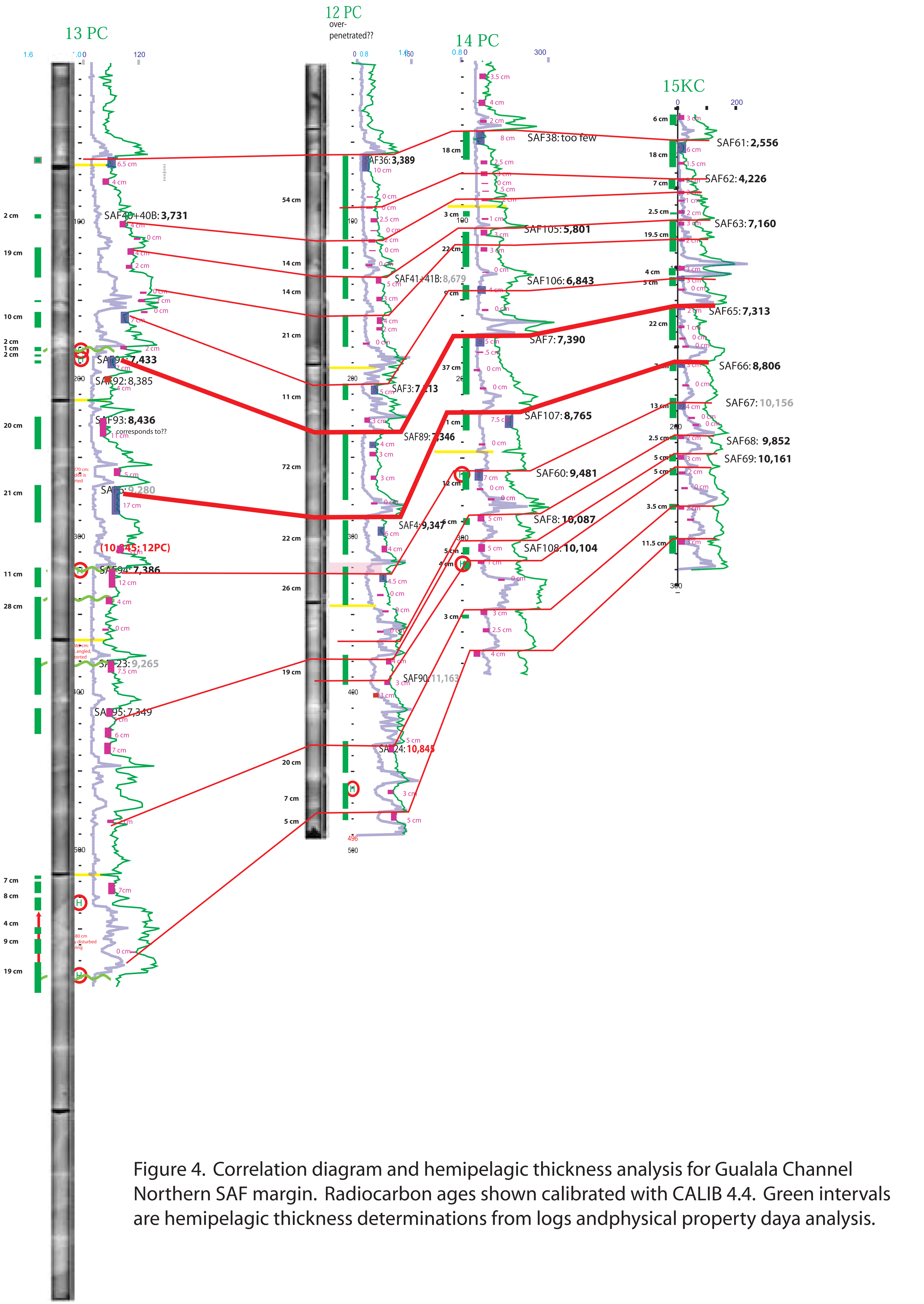

Figure 4. Correlation diagram and hemipelagic thickness analysis for Gualala Channel Northern SAF margin. Radiocarbon ages shown calibrated with CALIB 4.4. Green intervals are hemipelagic thickness determinations from logs andphysical property daya analysis.

since correlation between more than two channels implies linkages that are difficult to explain without an earthquake. We use these correlations, though their explanation is as yet uncertain.

Hemipelagic and radiocarbon Oxcal Methods Results

The tectonic setting of the northern California margin has been widely studied onshore, and turbidites offshore of this region have also been demonstrated to correlate well with the onshore earthquake record even though no good datum such as the Mazama Ash or colour change of Pleistocene to Holocene hemipelagic sediment have been found (Goldfinger et al., 2003a; 2003b). To aid in the analysis of seismo-turibidtes, the objective of the project has been a comparison of turbidite ages, frequencies, and recurrence intervals using two methods applied previously in Cascadia: 1) radiometric dating, based on radiocarbon ages of Foraminifera in the hemipelagic sediment just below each turbidite modified by Oxcal (see FY2005 undertaken) (^{14}C method), and 2) relative dating, based on the measure of the time interval between two turbidites, using hemipelagic sediment thickness and sedimentation rate (H method). These two approaches provide complimentary semi-independent methods to determine turbidite recurrence times. We focus on the H method to refine turbidite ages, determine the most accurate recurrence time history and frequency of turbidites and show the dominant control by earthquake triggering in the active tectonic margins as the northern California. The hemipelagic thickness analysis is being applied to the cores 49PC, 49TC, 54 Kasten core (KC) and 50 box core (BC) of the Noyo Channel key site on the northern California Margin (Figure 4).

Contributions to paleoseismic and human hazards studies on the northern San Andreas Fault (SAF)

Our study of the offshore NSAF system has developed the first extensive data set to infer average recurrence times for paleoseismic turbidites on the northern California margin and compare them with the onshore paleoseismic record, as well as the paleoseismic turbidites of the Cascadia margin. Great earthquakes on the northern California margin are greater than twice as frequent on average (200 yr) as those on the northern Cascadia Subduction Zone margin (~ 550 yr) and this is corroborated by the onland record . At Olema, 45 km north of San Francisco, Niemi and Hall (1992) estimate that if the 4-5 m slip event recorded in 1906 was characteristic, the recurrence time for such events would be 221±40 yr. Both our data and 10 new ages from the Vendata site and sites near Fort Ross suggest an average recurrence interval of ~200-230 yr. Consequently, we have the potential to go back in time using both the turbidite and onshore paleoseismic records to establish a more complete model of earthquake recurrence times to be applied in different active continental margin settings.

Continuing Work

Event correlation and ^{14}C dating

We continue our radiocarbon dating and analysis of physical property signatures as we work toward a stratigraphic framework for the Northern San Andreas System. With our colleagues at University of Granada, we are working with a semi-independent time series for SAF events based on the hemipelagic sediment thickness deposited between turbidite events. The methods used are more fully described in the companion University of Granada Report. The volume of samples and limited funding precludes a quantitative grain size or mineralogic analysis of hemipelagic thickness for each event in each core. At OSU, we are using density, color reflectance, and magnetics data as a proxy for determination of the turbidite tail-hemipelagic boundary to enhance the hemipelagic sediment analysis. We do this in two ways: 1) Magnetic susceptibility color reflectance, and density plots are compared with the logged hemipelagic intervals. These three datasets demonstrate that these tail-hemipelagic boundary can in most cases be accurately determined from the inflection point where fining upward turbidite tail clay grades upward into hemipelagic sediment. In the physical property plots, this point is marked by a flattening of all three curves (susceptibility, density, and RGB variance from the digital imagery) at this point. This estimate is effective in ~ 70% of the turbidite events. 2) After arriving at a final determination of hemipelagic thickness as above, we plot cumulative hemipelagic thickness in the core vs. age. These plots reflect the near constant local sedimentation rate, which changes subtly if at all during the Holocene for most sites. Sedimentation rates can be derived from regression of these data, and are in turn used to make corrections to the 14C ages due to the thickness of sample used. These plots are also used to calculate ages based on sedimentation rates for which 14C ages can’t be determined for whatever reason. An example is shown in **Figure 4** from Gualala Channel. **Figure 5** shows detail of the calculation of the age of the uppermost two events from Noyo Channel using these methods and radiocarbon

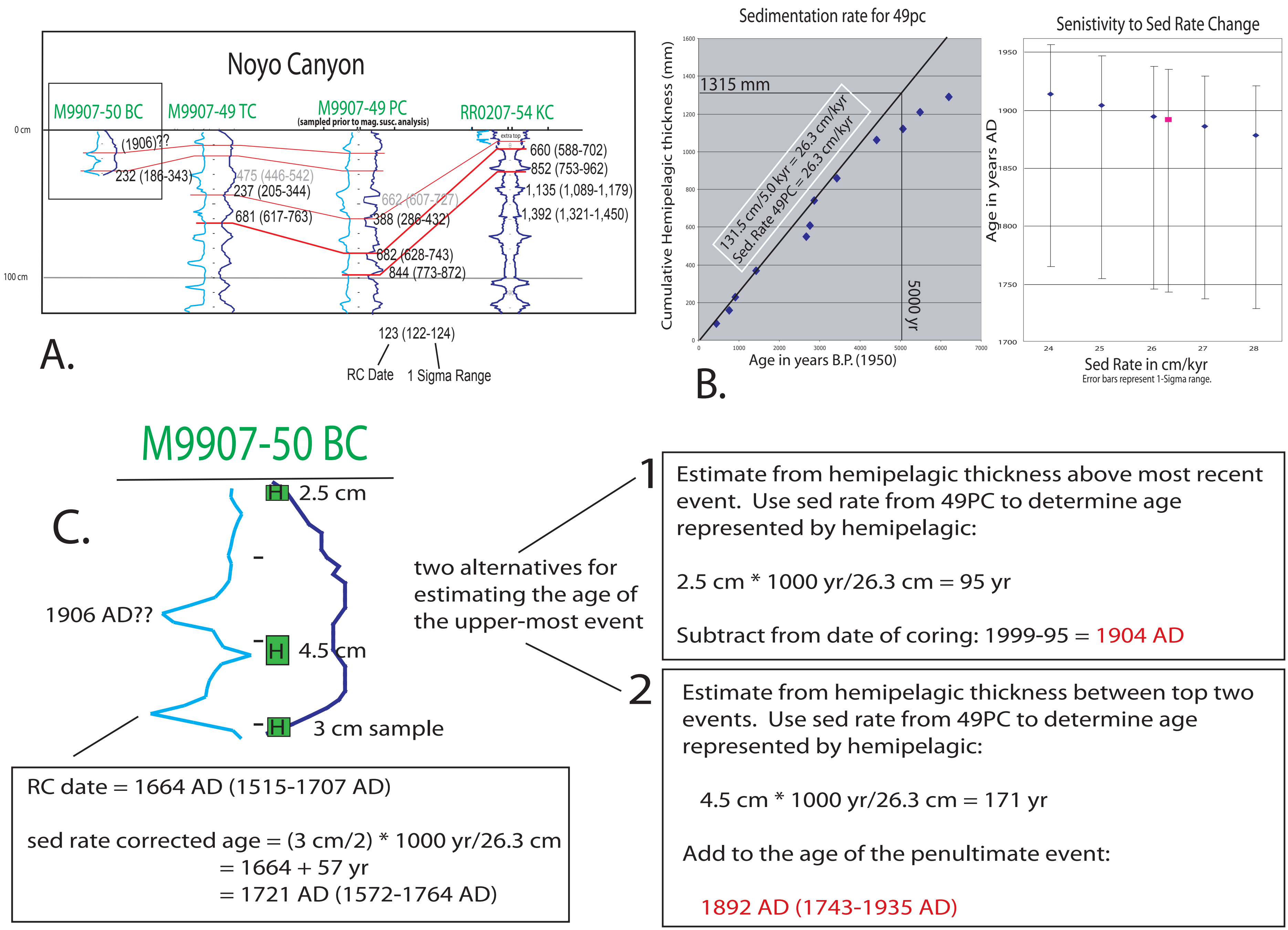

Figure 5. A. Core top correlation of the youngest SAF events in Noyo Channel. B. Regression determined sedimentation rate calculation for Noyo Channel, and sensitivity to sedimentation rate change. C. Calculation of ages of uppermost two events and correlation to 1906.

ages. The hemipelagic age for the 1906 earthquake is calculated by two methods to be 1892, or 1904 respectively (omitting errors analysis for this report). This serves as a check on the hemipelagic methods, which work very well for events where basal erosion is not a factor.

Clustering and possible temporal relationship to Cascadia events

Figure 6a shows time series for both well dated Cascadia events, and SAF events dated thus far at Noyo Channel. We have had a concern that the southernmost Cascadia margin might generate turbidites in Noyo Channel ~ 90 km away. While we find that the overall recurrence interval at Noyo is consistent with land paleoseismologic sites along the SAF, we also note that several events in Noyo Channel cannot be distinguished from Cascadia events based on ^{14}C results. We also observe that the as yet incomplete time series for the SAF appears to contain clusters of events in it's northern reach at Noyo Channel. This result appears robust regardless of whether some Cascadia events are also recorded. This exciting result suggests that there may be a stress linkage between the two great fault systems. This should not be surprising given what recent work on stress triggering has revealed about fault interactions around the world. We have modeled the stress interaction between Cascadia and the SAF using the Coulomb stress code of Shinji Toda and Ross Stein to examine the expected relationship between a 1906- type rupture and the Cascadia Subduction zone. This preliminary model suggests that SAF events should increase the Coulomb stress on the seaward part of the southern Cascadia plate interface, thus bringing it closer to failure, though it would unload the downdip portion of the fault. The reverse scenario is also true, where Cascadia thrust events can increase the Coulomb failure stress on the Northern San Andreas fault. This result was shown at the AGU Fall meeting in San Francisco (**Figure 6b**). While very preliminary, these results suggest a stress linkage between the two systems that is consistent with the temporal relationship we see in the turbidites. This is also consistent with, though not necessarily related to, the Cascadia paleoseismic record, which shows that additional events occur along the southern Cascadia margin relative to the number of margin wide great earthquakes.

Non-Technical Summary

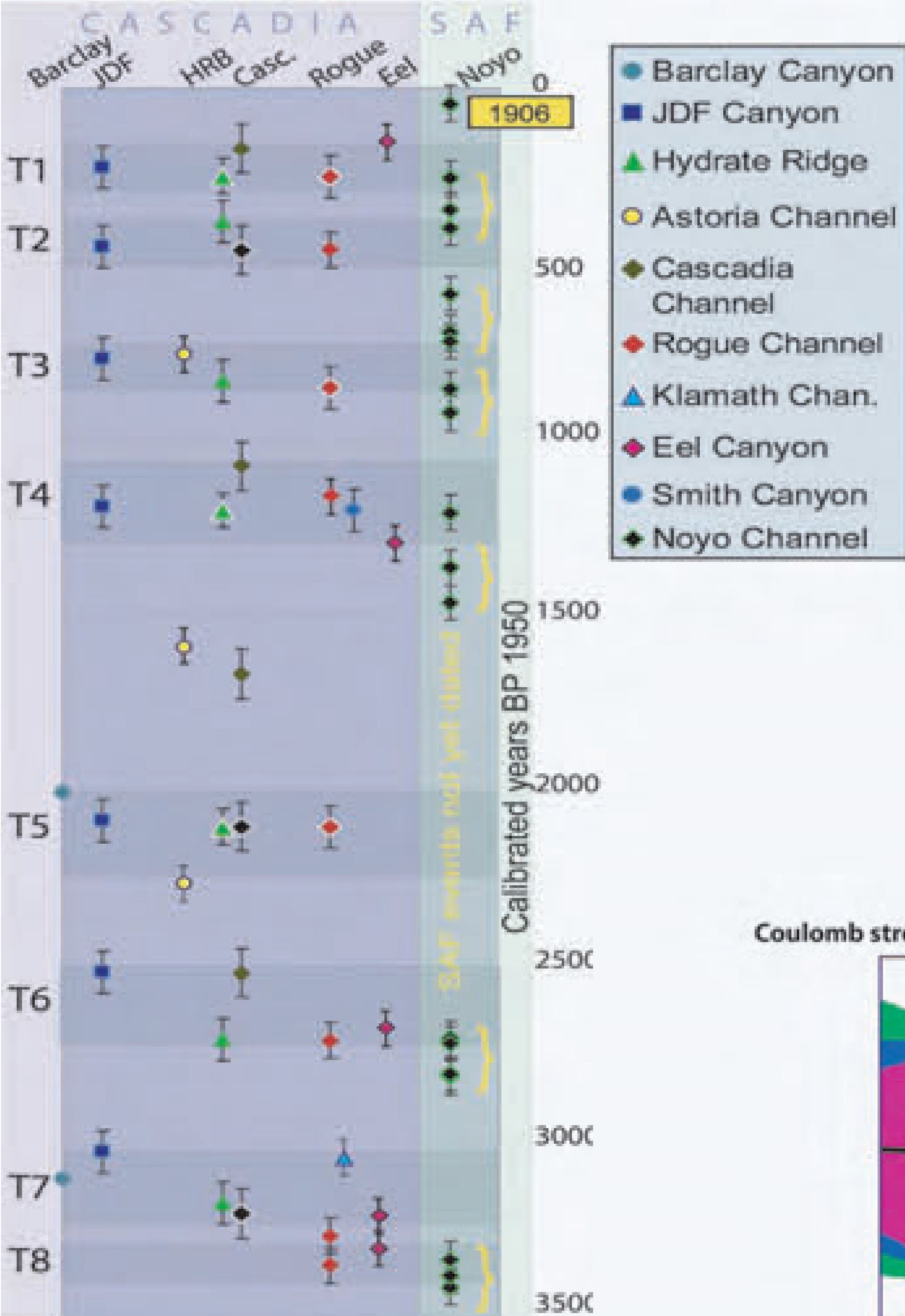

Figure 6a. Cascadia time series is shown at left, alongside the age sequence available thus far for Noyo Canyon along the northern SAF on the right. Noyo may have captured both SAF and Cascadia events. Moreover, SAF clustering is also suggested, and this figure suggests a temporal link between the two faults. Clusters of SAF events seem to precede Cascadia events, though additional dates are needed to test this model.

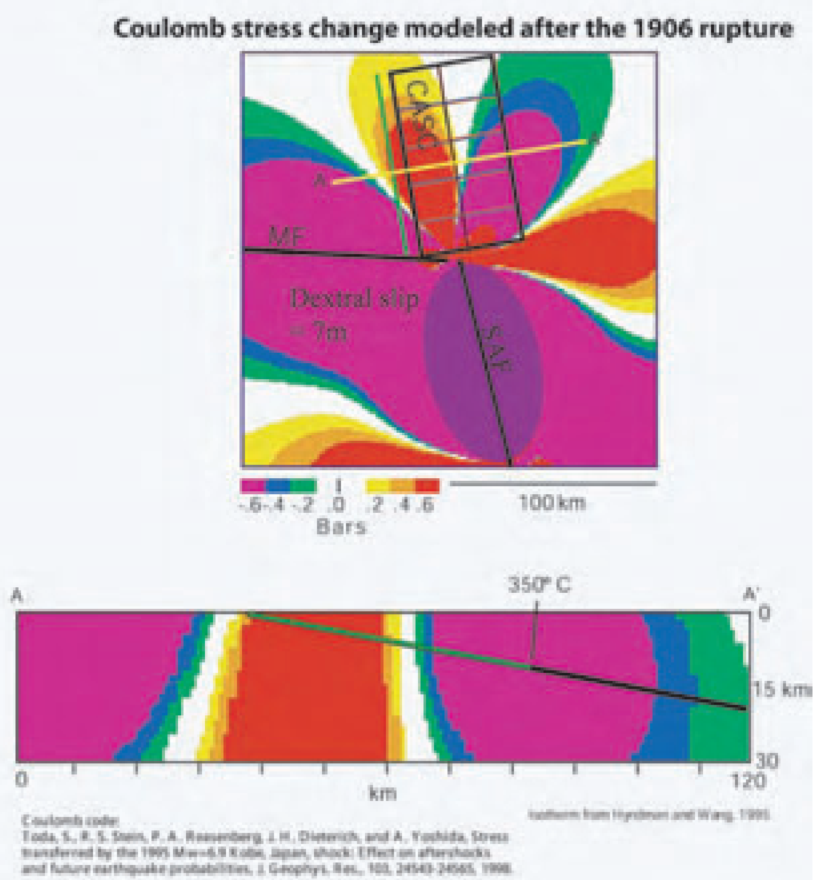

Figure 6b. Preliminary Coulomb stress modeling models suggests SAF 1906-type ruptures should place the southern, outboard part of the Cascadia coupled zone closer to failure

R/V Revelle San Andreas Fault Zone Turbidite Coring Cruise 2002: RC Sample Data

= on sampling diagram = to be resampled = Action Pending = caution 6478-7842 = multiple intersection on calibration curve

coarse fraction at OSU, returned from Boettcher, underlined

Samp. No.	Cruise No.	Core No.	Depth cm.	thickness	Wet samp. g	Sieved 63 m	Date Sent 2 Dick	Foram Est.	Foram Count	Foram Wt.(mg.)	Date CF Returned	Date Foram Vials Returned	ship 2 AMS lab	CAMS #	AMS Age RCYBP	+ -	AMS age Calib. 4.4 ? (1950) or /	Range 1 sigma
SAF1	RR0207	6PC	168-171	3	192	X	11/25/2003	>1000	819	6.6	1/8/2004	1/8/2004	1/9/2004	103904	9680	51.9	10016	9921-10146
SAF2	RR0207	6PC	263.5-266.5	3	250	X	11/25/2003	>1000	1124	7.2	1/8/2004	1/8/2004	1/9/2004	103905	11320	51.9	12468	12321-12653
SAF3	RR0207	12PC	204-207	3	212	X	11/25/2003	>700	1212	4.3	1/8/2004	1/8/2004	1/9/2004	103906	7030	77.4	7213	7142-7305
SAF4	RR0207	12PC	291-294	3	217	X	11/25/2003	>1000	758	4.5	1/8/2004	1/8/2004	1/9/2004	103907	9175	55.8	9347	9288-9483
	RR0207	12PC	294-297	3	223	X												
SAF5	RR0207	13PC	157-160	3	182	X	11/19/2003	>1000	1021	4.5	1/8/2004	1/8/2004	1/9/2004	103908	8935	55.8	9055	8937-9085
SAF6	RR0207	13PC	267.5-270.5	3	240	X	11/25/2003	>1000	937	5.0	1/8/2004	1/8/2004	1/9/2004	103909	9105	51.9	9280	9286-9430
SAF7	RR0207	14PC	174-177	3	193	X	11/25/2003	>800	1048	5.8	1/8/2004	1/8/2004	1/9/2004	103910	7225	51.9	7390	7335-7430
SAF8	RR0207	14PC	289-292	3	179	X	11/19/2003	>1000	901	6.9	1/8/2004	1/8/2004	1/9/2004	103911	9775	51.9	10087	9966-10222
SAF9	RR0207	18PC	115.5-118.5	3	217	X	11/25/2003	>800	1032	2.1	1/8/2004	1/8/2004	1/9/2004	103912	7290	68.5	7452	7395-7517
SAF10	RR0207	18PC	285-288	3	302	X	11/19/2003	>1000	1100	6.9	1/8/2004	1/8/2004	1/9/2004	103913	12625	55.8	13733	13515-13689
SAF11	RR0207	20PC	118-121	3	168	X	11/25/2003	>800	1207	3.8	1/8/2004	1/8/2004	1/9/2004	103914	6220	51.9	6291	6240-6350
Dick will combine these two samples:																		
SAF12	RR0207	20PC	286.5-289.5	3	264.5	X	11/19/2003	450			1/8/2004	1/8/2004						
SAF12B	RR0207	20PC	289.5-292.5	3	290	X	2/3/2004	900			Dick has	HOLD	Q: hi forams??					
SAF13	RR0207	25GC	102-105	3	228	X	11/19/2003	>1000	1064	4.4	1/8/2004	1/8/2004	1/9/2004	103915	17010	77.4	19293	18973-19598
SAF14	RR0207	25GC	223.5-226.5	3	270	X	11/19/2003	300	<--too few		1/8/2004	1/8/2004	abort					
	RR0207	26PC	175.5-180.5	5	193	X	11/19/2003											
SAF15	RR0207	26PC	291-295	4	143	X	11/19/2003	>800	1143	4.9	1/8/2004	1/8/2004	1/9/2004	103916	17015	59.9	19299	18984-19598
SAF16	RR0207	31PC	138-141	3	240	X	11/19/2003	200	<--too few		1/8/2004	1/8/2004	abort					
SAF17	RR0207	31PC	284-287	3	204	X												
SAF18	RR0207	33PC	280.5-283.5	3	203	X	11/25/2003	>1000	1120	7.8	1/8/2004	1/8/2004	1/9/2004	103917	10205	51.9	10632	10674-10810
Dick will combine these two samples:																		
SAF19	RR0207	36PC	66-69	3	140	X	11/25/2003	700	648	1.3	1/8/2004	3/10/2004	3/10/2004	105311	4350	45	4013	3928-4084
SAF19B	RR0207	36PC	69-71	2	144	X	2/3/2004	250	242	0.6	3/10/2004	3/10/2004	3/10/2004	together				
SAF20	RR0207	36PC	277.5-280.5	3	240	X	11/25/2003	>1000	829	6.2	1/8/2004	1/8/2004	1/9/2004	103918	9040	51.9	9239	9268-9406
SAF21	RR0207	45PC	85-88	3	183	X	11/25/2003	500	616	2.0	1/8/2004	1/8/2004	1/9/2004	103919	7570	124.5	7693	7572-7800
SAF22	RR0207	06PC	366.5-369.5	3	229	X	2/3/2004	>1000	843	5.8	3/10/2004	3/10/2004	3/10/2004	105312	13490	60	14901	?
SAF23	RR0207	13PC	378.5-381.5	3	279	X	2/3/2004	>1000	1137	7.7	3/10/2004	3/10/2004	3/10/2004	105313	9080	60	9265	
SAF24	RR0207	12PC	432.5-435.5	3	242	X	2/3/2004	>900	1004	2.9	3/10/2004	3/10/2004	3/10/2004	105314	10390	60	10845	10471-10885
SAF25	RR0207	14PC	435-438	3	251	X	2/3/2004	<100	<--too few		Dick has	HOLD	abort					
SAF26	RR0207	25GC	355.5-358.5	3	279	X	2/3/2004	>1000	833	8.9	3/10/2004	3/10/2004	3/10/2004	105315	14930	60	16898	16643-17141
SAF27	RR0207	26PC	403-410	7	205	X	2/3/2004	>1000	1153	8.8	3/10/2004	3/10/2004	3/10/2004	105316	17760	70	20154	19823-20474
SAF28	RR0207	18PC	408-412	4	267	X	2/3/2004	1000	1041	4.9	3/10/2004	3/10/2004	3/10/2004	105317	13860	80	15634	15397-15958
SAF29	RR0207	31PC	403-406	3	296	X	2/3/2004	<50	<--too few		Dick has	HOLD	abort					
SAF30	RR0207	33PC	418.5-421.5	3	235	X	2/3/2004	>1000	1163	5.2	3/10/2004	3/10/2004	3/10/2004	105318	11380	45	12503	12341-12522
Dick will combine these two samples:																		
SAF31	RR0207	33PC	98-101	3	203	X	2/3/2004	450	1073	4.9	6/14/2004	6/14/2004	6/14/2004	107632	6290	35	6354	6302-6395
SAF31B	RR0207	33PC	101-104	3	234	X	5/26/2004	>1000										
Dick will combine these two samples:																		
SAF32	RR0207	54KC	4.5-7.0	2.5	339	X	4/5/2004	550	1133	2.1		6/14/2004	6/14/2004	107633	15555	45	757	685-799
SAF32B	RR0207	54KC	deeper, same interval		272	X	5/6/2004	700										
SAF33	RR0207	54KC	16.5-19.5	3	295	X	4/5/2004	>1000	1064	3.5	5/1/2004	5/1/2004	5/6/2004	106623	1760	90	968	869-1079
SAF34	RR0207	54KC	245-248	3	276	X	4/5/2004	>1000	998	6.3	5/1/2004	5/1/2004	5/6/2004	106624	5605	40	5624	5575-5666
SAF35	RR0207	54KC	257-260	3	292	X	4/5/2004	>1000	1033	5.9	5/1/2004	5/1/2004	5/6/2004	106625	5755	40	5786	5727-5854
SAF36	RR0207	12PC	59-62	3	200	X	4/5/2004	950	975	4.0	5/1/2004	5/1/2004	5/6/2004	106626	3850	40	3389	3338-3443
SAF37	RR0207	13PC	58.5-61.5	3	187	X	4/5/2004	500	771	1.5	6/14/2004	<--too few	abort					
SAF37B	RR0207	13PC	61.5-64	2.5	189	X	5/6/2004	220										
SAF38	RR0207	14PC	46-49	3	203	X	4/5/2004	250	<--too few	abort								
SAF39	RR0207	18PC	44-47	3	192	X	5/6/2004	1000	1071	4.5	6/14/2004	6/14/2004	6/14/2004	107634	6420	40	6498	6431-6559
Dick will combine these two samples:																		
SAF40	RR0207	13PC	96-99	3	269	X	5/6/2004	550	1004	2.5	6/14/2004	6/14/2004	6/14/2004	107635	4135	40	3731	3671-3807
SAF40B	RR0207	13PC	99-101	2	146	X	5/26/2004	550										
Dick will combine these two samples:																		
SAF41	RR0207	12PC	136-139	3	211	X	5/6/2004	400	1014	3.3	6/14/2004	6/14/2004	6/14/2004	107636	8525	40	8679	8586-8762
SAF41B	RR0207	12PC	139-142	3	224	X	5/26/2004	500										
SAF42	RR0207	14PC	95-98	3	232	X	5/6/2004	300	above turbic	abort	7/12/2004							
SAF43	RR0207	18PC	82-85	3	251	X	5/6/2004	300	<--too few	abort	7/12/2004							
SAF44	RR0207	25GC	66-69	3	263	X	5/6/2004	>1000	1115	2.55	6/23/2004	6/23/2004	6/23/2004	WHERE????				
SAF45	RR0207	26PC	55-58	3	195	X	5/6/2004	>1000	1092	3.3	6/23/2004	6/23/2004	6/23/2004	108661	4830	45	4676	4608-4779
Dick will combine these two samples:																		
SAF46	RR0207	33PC	41-44	3	190	X	5/6/2004	300	<--too few	abort	7/12/2004	9/7/2004	9/7/2004					
SAF46B	RR0207	33PC	44-47	3	172	X	5/26/2004	150										
SAF47	RR0207	36PC	15.5-18.5	3	182	X	5/6/2004	250	<--too few	abort	7/12/2004							
SAF48	RR0207	45PC	21.5-24.5	3	147	X	5/6/2004	>1000	907	4.02	6/23/2004	6/23/2004	6/23/2004	108662	2025	45	1236	1185-1282
Dick will combine these two samples:																		

SAF49	RR0207	54KC	50-53	3	259	X	6/4/2004	300	1115	2.0	9/14/2004	9/7/2004	9/7/2004	110150	2300	40	**1508**	**1437-1566**
SAF49B(77)	RR0207	54KC	50-53	3	261.5	X	8/10/2004	850			9/14/2004							
SAF50	RR0207	54KC	74.5-77.5	3	274	X	6/4/2004	100	<--too few	abort	7/12/2004							
SAF51	RR0207	54KC	133.5-136.5	3	259.5	X	6/4/2004	370	1124	3.0	11/7/2004	11/7/2004	########	112486	3150	40	**2556**	**2479-2663**
SAF51B	RR0207	54KC	133.5-136.5	3	497	X	10/8/2004	750										
SAF52	RR0207	18PC	92-96	4	253	X	5/26/2004	>1000	1062	4.0	6/23/2004	6/23/2004	6/23/2004	108663	6000	45	**6053**	**5981-6116**
SAF53	RR0207	06PC	80-83	3	265	X	5/26/2004	>1000	1013	4.4	6/23/2004	6/23/2004	6/23/2004	108664	6430	35	**6510**	**6443-6565**
SAF54	RR0207	06PC	156-159	3	289	X	5/26/2004	>1000	921	6.1	6/23/2004	6/23/2004	6/23/2004	108665	9220	45	**9425**	**9372-9618(9095-9**
Dick will combine these two samples:																		
SAF55	RR0207	54KC	143.5-146.5	3	273	X	6/4/2004	600	1079	3.3	9/14/2004	9/7/2004	9/7/2004	110149	3330	40	**2761**	**2715-2799**
SAF55B(80)	RR0207	54KC	143.5-146.5	3	200	X	8/10/2004	1000			9/14/2004							
SAF56	RR0207	54KC	154-157	3	273.5	X	6/4/2004	>1000	860	5.0	7/2/2004	7/6/2004	7/6/2004	108666	3425	40	**2847**	**2777-2896**
SAF57	RR0207	54KC	215-218	3	282.5	X	6/4/2004	1000	1003	6.4	7/2/2004	7/6/2004	7/6/2004	108667	4815	40	**4657**	**4570-4726**
SAF58	RR0207	54KC	227-230	3	258	X	6/4/2004	>1000	999	5.0	7/2/2004	7/6/2004	7/6/2004	108668	5270	40	**5260**	**5191-5323**
SAF59	RR0207	18PC	231-235	4	249	X	6/4/2004	>1000	1082	4.6	7/2/2004	7/6/2004	7/6/2004	108669	11280	60	**12410**	**12292-12642**
SAF60	RR0207	14PC	259-263	4	248.5	X	6/4/2004	>1000	564	6.9	7/2/2004	7/6/2004	7/6/2004	108670	9260	40	**9481**	**9405-9636**
SAF61	RR0207	15KC	19.5-22.5	3	315	X	6/17/2004	>1000	778	5.2	7/2/2004	7/6/2004	7/6/2004	108671	3150	40	**2556**	**2479-2663**
SAF62	RR0207	15KC	41-44	3	371	X	6/17/2004	>1000	1045	3.9	7/12/2004	7/12/2004	7/12/2004	108672	4500	40	**4226**	**4142-4298**
SAF63	RR0207	15KC	68.5-71.5	3	270	X	6/17/2004	>1000	932	5.5	7/12/2004	7/12/2004	7/12/2004	108673	6975	45	**7160**	**7129-7231**
SAF64	RR0207	15KC	105-109	3	360	X	6/17/2004	400	conflict in numbers of forams									
SAF64B	RR0207	15KC	105-109	4	470	X	10/9/2004	>1000										
SAF65	RR0207	15KC	123-126	3	254	X	6/17/2004	>1000	962	5.8	7/12/2004	7/12/2004	7/12/2004	108674	7130	40	**7313**	**7261-7361**
SAF66	RR0207	15KC	159.5-162.5	3	279	X	6/17/2004	>1000	846	5.9	7/12/2004	7/12/2004	7/12/2004	108675	8645	40	**8806**	**8740-8900**
SAF67	RR0207	15KC	206-209	3	267	X	6/17/2004	>1000	881	8.1	7/12/2004	7/12/2004	7/12/2004	108676	9835	40	**10156**	**10014-10308**
SAF68	RR0207	15KC	217.5-220.5	3	263	X	6/17/2004	>1000	885	8.1	7/12/2004	7/12/2004	7/12/2004	108677	9840	40	**10161**	**10017-10310**
SAF69	RR0207	15KC	181.5-184.5	3	272	X	6/17/2004	>1000	936	7.8	7/12/2004	7/12/2004	7/12/2004	108678	9535	40	**9852**	**9769-10000**
SAF70	RR0207	33PC	135-138	3	265	X	7/22/2004	>1000	1059	4.5	8/11/2004	8/11/2004	8/20/2004	110143	6670	40	**6781**	**6722-6845**
SAF71	RR0207	33PC	149.5-152.5	3	180	X	7/22/2004	>1000	1063	4.2	8/30/2004	8/30/2004	9/2/2004	110144	7145	40	**7326**	**7271-7372**
SAF72	RR0207	33PC	189-192	3	227	X	7/22/2004	>1000	751	5.1	8/30/2004	8/30/2004	9/2/2004	110145	8685	40	**8857**	**8799-8929**
SAF73	RR0207	33PC	214-217	3	211	X	7/22/2004	>1000	878	6.6	8/30/2004	8/30/2004	9/2/2004	110146	9290	40	**9517**	**9426-9567**
SAF74	RR0207	33PC	230.5-233.5	3	197	X	7/22/2004	>1000	873	5.7	8/30/2004	8/30/2004	9/2/2004	110147	9620	40	**9975**	**9819-10125**
SAF75	RR0207	33PC	240.5-243.5	3	176.5	X	7/22/2004	>1000	859	5.8	8/30/2004	8/30/2004	9/2/2004	110148	9785	40	**10098**	**9978-10231**
SAF76	RR0207	54KC	34-37	3	331.5	X	8/10/2004	1000	1115	2.2	9/14/2004	9/7/2004	9/7/2004	110151	2040	40	**1251**	**1205-1295**
SAF78	RR0207	54KC	102-105	3	264	X	8/10/2004	250	<--too few									
SAF78B	RR0207	54KC	102-105	3	418	X	10/8/2004	200										
SAF79	RR0207	54KC	118-121	3	252	X	8/10/2004	>1000	979	2.6	9/14/2004	9/7/2004	9/7/2004	110152	3910	40	**3453**	**3385-3511**
SAF81	RR0207	54KC	169.5-172.5	3	262	X	8/10/2004	800	1146	3.0	9/14/2004	9/7/2004	9/7/2004	110153	5830	40	**5861**	**5797-5918**
SAF82	RR0207	54KC	182-185	3	314	X	8/10/2004	1000	1007	3.8	9/14/2004	9/14/2004	9/15/2004	110425	3880	45	**3421**	**3352-3471**
SAF83	RR0207	54KC	188.5-191.5	3	258.5	X	8/10/2004	>1000	1073	3.7	9/14/2004	9/14/2004	9/15/2004	110426	4095	40	**3679**	**3609-3751**
SAF84	RR0207	54KC	201-204	3	272	X	8/10/2004	>1000	1010	4.0	9/14/2004	9/14/2004	9/15/2004	110427	4395	40	**4075**	**3990-4141**
SAF85	RR0207	54KC	238.5-241.5	3	287.5	X	8/10/2004	>1000	1007	5.1	9/14/2004	9/14/2004	9/15/2004	110428	5285	40	**5282**	**5210-5338**
SAF86	RR0207	54KC	278.5-281.5	3	255.5	X	8/10/2004	>1000	1045	5.2	9/14/2004	9/14/2004	9/15/2004	110429	6630	40	**6735**	**6668-6786**
SAF87	RR0207	06PC	134-137	3	163	X	8/25/2004	?	836	5.5	9/28/2004	9/28/2004	9/29/2004	110430	8935	40	**9053**	**8937-9084**
SAF88	RR0207	18PC	216-219	3	187	X	8/25/2004	?	1071	3.0	9/28/2004	9/28/2004	9/29/2004	110431	10960	60	**11742**	**11600-11964**
SAF89	RR0207	12PC	234-237	3	115.5	X	9/7/2004	>1000	1038	3.4	10/11/2004	10/11/2004	########	110805	7170	45	**7346**	**7302-7403**
SAF90	RR0207	12PC	390-393	3	184	X	9/7/2004	>1000	1006	6.3	10/11/2004	10/11/2004	########	110806	10585	40	**11163**	**11093-11333**
SAF91	RR0207	13PC	187-190	3	210	X	9/7/2004	900	1046	3.2	10/11/2004	10/11/2004	########	110807	7270	60	**7433**	**7371-7497**
SAF92	RR0207	13PC	199.5-202.5	3	224	X	9/7/2004	>1000	1019	3.5	10/11/2004	10/11/2004	########	110808	8275	45	**8385**	**8329-8434**
SAF93	RR0207	13PC	224.5-227.5	3	218	X	9/7/2004	>1000	919	5.1	10/11/2004	10/11/2004	########	110809	8325	45	**8436**	**8371-8491**
SAF94	RR0207	13PC	319.5-322.5	3	225	X	9/7/2004	>1000	1026	3.7	10/11/2004	10/11/2004	########	110810	7220	45	**7386**	**7327-7428**
SAF95	RR0207	13PC	411.5-414.5	3	260	X	9/7/2004	>1000	1011	2.9	10/11/2004	10/11/2004	########	110811	7175	45	**7349**	**7306-7405**
SAF96	RR0207	20PC	169-172	3	168	X	9/7/2004	>1000	850	3.9	10/28/2004	10/28/2004	########	111269	8640	60	**8793**	**8709-8897**
SAF97	RR0207	33PC	261.5-264.5	3	183	X	9/7/2004	900	1030	3.5	10/28/2004	10/28/2004	########	111270	10080	45	**10479**	**10302-10612**
SAF98	RR0207	36PC	136.5-139.5	3	157	X	9/7/2004	450	<--too few									
SAF99	RR0207	36PC	221.5-224.5	3	162	X	9/7/2004	>1000	1038	2.7	10/28/2004	10/28/2004	########	111271	7895	45	**8002**	**7934-8053**
SAF100	RR0207	45PC	102-105	3	199	X	9/7/2004	>1000	896	5.3	10/28/2004	10/28/2004	########	111272	8165	50	**8276**	**8211-8338**
SAF101	RR0207	45PC	124-127	3	142.5	X	9/7/2004	>1000	853	5.9	10/28/2004	10/28/2004	########	111273	8740	60	**8898**	**8827-8967**
SAF102	RR0207	45PC	145-148	3	182	X	9/7/2004	>1000	871	8.4	10/28/2004	10/28/2004	########	111274	9180	30	**9352**	**9295-9484**
SAF103	RR0207	45PC	169.5-172.5	3	175	X	9/7/2004	>1000	1022	6.1	10/28/2004	10/28/2004	########	111275	10040	35	**10458**	**10412-10597**
SAF104	RR0207	13TC	49-52	3	194	X	11/18/2004	350	<--too few		Dick	Dick						
SAF105	RR0207	14PC	106.5-109.5	3	181	X	11/18/2004	>1000	1067	5.9	12/6/2004	12/6/2004	12/9/2004	112487	5775	50	**5801**	**5740-5874**
SAF106	RR0207	14PC	136.5-139.5	3	157	X	11/18/2004	900+	1158	3.1	12/6/2004	12/6/2004	12/9/2004	112488	6725	35	**6843**	**6779-6902**
SAF107	RR0207	14PC	222-225	3	189	X	11/18/2004	>1000	979	6.7	12/6/2004	12/6/2004	12/9/2004	112489	8605	45	**8765**	**8678-8856**
SAF108	RR0207	14PC	306-309	3	224	X	11/18/2004	>1000	983	7.4	12/6/2004	12/6/2004	12/9/2004	112490	9790	40	**10104**	**9983-10238**
SAF109	RR0207	18TC	53-56	3	192	X	11/18/2004	900+	1011	4.0	12/6/2004	12/6/2004	12/9/2004	112491	6385	40	**6457**	**6395-6517**

Cores from Noyo Channel on the ocean floor off northern California have been studied for sand layers. These sand layers are thought to represent times when great earthquakes on the northern San Andreas Fault have shaken the continental margin, resulting in landslides that transport the sand down the channels. We have determined the ages of these layers, and these ages suggest that major earthquakes have occurred on average every ~ 200 yr for the past ~ 2600 years with a minimum time of ~ 175 years between earthquakes. However, more cores and land records must be examined to verify this preliminary record of earthquakes.

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Availability of Data

All processed AMS radiocarbon age data is available in excel tables. Analogue records of core lithologic data are archived at the OSU core repository where the cores are stored.

Additional interpretative data of core logs are available in Adobe Illustrator files that reside at both OSU and UGR. The general GIS data base of swath bathymetry, seismic profiles, core locations etc. resides at OSU. The contacts for all the aforementioned data sets are Hans Nelson (odp@ugr.es), Julia Gutiérrez Pastor (juliagp@ugr.es) and Chris Goldfinger (gold@coas.oregonstate.edu) at the UGR and OSU addresses listed on the first page.